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THE USE OF CRUMB RUBBER IN ASPHALT MIXTURES USING THE DRY PROCESS

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ABSTRACT

The modification process of hot mix asphalts in which crumb rubber is initially mixed with the mineral aggregates before the addition of the binder is known as dry process. This process has as main advantages the use of conventional mixing plants and, at least in principle, has no limitation of the incorporated rubber content. The aim of this paper is to study the influence of the incorporated crumb rubber content in the mechanical behavior of dense graded mixes (grade envelope C of Brazilian specification DNER-ES 313/97). For this purpose, laboratory tests were carried out to determine the main properties to be used in numerical analyses of a structure of flexible pavement executed with that type of asphalt mixture. The mechanical properties of asphalt hot mixes used in the numerical analysis were determined by laboratory tests (stiffness modulus and fatigue life). The studied asphalt hot mixes were produced with a crumb rubber obtained by the milling process at ambient temperature and a straight binder AC 50/70 (classification by penetration). The incorporated rubber content varied from 2% up to 3,6% in relation to the mineral aggregate mixture. For the sake of comparison, a conventional asphalt mixture produced with straight binder AC 50/70 and an asphalt-rubber hot mix produced by wet process were also studied. The results showed that the asphalt hot mixes modified with crumb rubber by dry process presented a significant improvement in terms of mechanical behavior in relation to conventional asphalt hot mixes, especially in terms of increase of fatigue life, as can be observed in the numerical analysis performed.

KEY WORDS

Asphalt-rubber, dry process, crumb rubber

INTRODUCTION

The incorporation of materials as crumb rubber obtained from ground tires in straight binder has as main purpose to improve the mechanical behavior of asphalt hot mixes used in the wearing courses of flexible pavements. The main improvements observed are increase of flexibility, fatigue life and resistance to rutting (1).

There are basically two processes to modify the asphalt hot mixes with crumb rubber: in the first process, known as wet process, the asphalt hot mixes are manufactured with straight binder modified with crumb rubber under certain time e temperature conditions; in the second process, known as dry process, the crumb rubber is initially mixed with a pre-heated mineral aggregate mixture, in which, the straight binder is introduced. Besides the dry and wet processes, there is a variant of the later called "terminal blend" (3).

Modified binders used in the wet process experience a sharp increase in viscosity with the increase in crumb rubber content. Therefore, the manufacturing procedure, such as binder pumping, limits the amount of crumb rubber that can be incorporated in the wet process. The norm ASTM D6114-97 fixes the maximum limit of viscosity in 5000 cP, although in practice this limit may be somewhat higher. In the dry process, on the other hand, there is no limitation of rubber content related to binder viscosity. If a limit is to exist, it will depend on the compactability of the whole mixture. Furthermore, simple conventional machinery can be used for mixing, spreading and compacting hot asphalt mixes produced via the dry process.

The objective of this paper is to investigate the influence of the crumb rubber content on the mechanical behavior of hot asphalt mixes produced by the dry process. Dense graded hot mixes, with aggregates fitting the grade envelope C of Brazilian DNER-ES 313/97 specification, were produced and tested in laboratory for the determination of their resilient moduli and fatigue life. For a comparative study, other mixes using the conventional process and a binder modified via the wet process were also produced and tested. The results were used in numerical analyses that simulated the behavior of a typical structure using these materials, so as to comparative their relative advantages.

ASPHALT RUBBER: MANUFACTURING PROCESSES

In the so called wet process, asphalt binder is heated to temperatures in the order of 190°C inside a tank hermetically closed. Then the hot binder is transported to an appropriate mixing tank, in which crumb rubber is added and mixed under certain time and temperature conditions. The interaction process generally takes between 1 and 4 hours and is facilitated by mechanical action of a shaft (4).

In the dry process, particles of crumb rubber are added to the mixture of mineral aggregates, before mixing with a conventional asphalt binder. The aggregates are initially heated to about 200°C. Then crumb rubber is added and mixed for about 15 seconds for homogenization. Finally, hot conventional binder is mixed as in the conventional HMA manufacturing plant.

The dimension of crumb rubber particles used in the dry process is generally bigger than for those used in the wet process. Besides, in the dry process, the crumb rubber substitutes part of the aggregate mineral, thus behaving more like an inert material (5).

Problems related to difficulties during compaction and lack homogeneity may result in poor reproducibility in field performance and premature failure in some cases, what may explain why asphalt mixes produced via the dry process is used to a lesser extent than others (5).

The term "asphalt-rubber" seems to be more appropriate for the wet process, while in the dry process there is initially an "aggregate-rubber" mixture to which conventional binder is added. Besides, there is a lot of controversy among many authors as to the occurrence or not of reaction between the asphalt binder and the crumb rubber in the dry process and even in the wet process.

According to Visser & Verhaeghe (4), there is no fusion between crumb rubber and the conventional asphalt binder in the dry process. Takallou & Takallou (3) share the same opinion and state that crumb rubber acts as an additive, not a modifier, even in the wet process. On the hand, Momm & Salini (6), based on observations using optical microscope, state that the crumb rubber is not inert and react with the hot binder during the time that they stay in contact during transportation operation, for instance.

It is supposed that possible reactions between rubber and binder in the dry process are dependent on the grain size distribution of the crumb rubber. Smaller rubber particles have larger specific surfaces what should facilitate contact and reaction with the binder, even during the shorter periods and lower temperature in which they are in contact, compared to the wet process.

Terminal blend asphalt-rubber is produced by the digestion of rubber in asphalt rubber at high temperatures in a remote plant. This process has been used in Texas, USA, since 1989, and generally uses a rubber content lower than those adopted in the dry and wet processes (3).

MATERIALS

Crumb rubber and straight binder

The crumb rubber used in the mixtures prepared for this paper was obtained by grinding unserviceable tires at ambient temperature (1). The tires comprised a mix 20% of which derived from trucks and 80% from passenger cars of different types and origins. The resulting crumb rubber has grain particles ranging between 0.5 mm and 2.0 mm. The grain size distribution per sieve, as well as that prescribed by the Arizona Department of Transport (ADOT), is shown in Table 1.

Table 1. Grain size distribution.

Mesh		Percentage passing		
#	**mm**	**ADOT**		**Crumb rubber**
Nº 4	4,75	100	100	100
Nº 8	2,36	100	99,9	99,9
Nº 10	2,00	100	96,8	96,8
Nº 16	1,18	65	47,7	47,7
Nº 30	0,60	20	18,7	18,7
Nº 50	0,30	0	7,5	7,5
Nº200	0,075	0	0	0

The conventional binder used to prepare the hot mixes is produced in Portugal and classified by penetration as CA 50/70. The physical properties of the conventional binder are shown in Table 2.

Table 2. Physical properties of the straight binder.

Property	CA 50/70
Penetration, ASTM D 5-95 (1/10 mm)	52,0
Softening point, ASTM D36-97 (ºC)	50,6

Aggregates

The granular aggregates used in this research were of granitic origin and include:

- Grade 1 crushed granitic stone: particle size 11 - 16 mm;
- Grade 0 crushed granitic stone: particle size 4 - 11 mm;
- Fine crushed granitic aggregate: particle size < 4 mm.

It was also used granitic filler available at the University of Minho, Portugal, where all laboratory tests were carried. The mixture of granular aggregates was dosed to fit the center of grade envelope C of the Brazilian specification DNER-ES 313/97. This aggregate grain distribution produces a dense graded continuous asphalt hot mix, recommended for use in flexible pavements. Table 3 presents the composition of the mixture that fits the specifications, as well as other properties of the granitic aggregates.

Table 3. Aggregate mixture.

Properties	Grade 1	Grade 0	Fine crushed	Filler
Composition (%)	10	30	55	5
Apparent unit weight (kN/m^3)	26,4	25,8	25,2	25,2
Grain unit weight (kN/m^3)	26,9	26,8	27,1	27,1
Water absorption (%)	0,77	1,39	-	-

ASPHALT HOT MIXES MODIFIED WITH CRUMB RUBBER

Definition, design and manufacturing process

The following types of hot mixes were prepared for this research:

- Conventional hot mix asphalt (HMA-C): aggregate mixture plus conventional binder CA 50/70;
- Modified Asphalt-rubber hot mix, wet process (HMAR-W): aggregate mixture plus modified binder composed of CA 50/70 and 21% of crumb rubber (reaction time of 60 minutes at a temperature of 170°C);
- Hot mix asphalt with crumb rubber, dry process (HMAR-D): mixture of aggregate and crumb rubber in variable contents plus conventional binder CA 50/70;

The binder content was determined using Marshall Method (DNER-ME 043/94) for all mixes. The optimal binder content was initially determined for the conventional (HMA-C) and modified asphalt-rubber (HMAR-W) mixes. From the dosage of the HMAR-W, it was possible to determine the content of conventional binder and crumb rubber to be initially used in the dry process (HMAR-D), so that all mixes had the same amount of isolated components.

Table 4 present the values of temperatures used to heat the binder and aggregates, as well as the compaction temperature for each mix. These temperatures were chosen taking in account the workability of the conventional and modified binders. It can be noted that mixes using the dry process used the same temperature conditions as the conventional ones.

Table 4. Temperatures for hot mixes preparation

Temperature of	**HMA-C**	**HMAR-D**	**HMAR-W**
Binder (°C)	160	160	170
Aggregates (°C)	177	177	190
Compaction (°C)	160	160-170	164

As the mechanical behavior of asphalt mixes is highly dependent on their volumetric properties (1), all mixes used in this paper used the binder content determined by the Marshall dosage method, but were compacted to the same conditions of voids. The reference value was that determined for the conventional HMA, which was a volume ratio Vv equal to 4.5%. The main objective of this procedure is to isolate the influence of the type of binder (conventional or modified asphalt-rubber) and rubber content (in the case of HMAR-D) in the mechanical behavior of the mixes. Table 5 presents properties of the conventional and asphalt-rubber dense mixes.

Table 5. Volumetric properties of the dense mixes.

Vomuletric property	**HMA-C**	**HMAR-W**
Apparent density (kN/m^3)	22,5	22,5
Void contents (%)	4,5	4,5
Void in the mineral aggregates (%)	20,1	19,3
Void-bitumen ratio (%)	77,6	76,7
Optimal binder content (%)	7,0	9,6

Taking the optimal binder content for wet process mix (HMAR-W), which was 9.6%, and considering that the modified asphalt-rubber binder contains 21% of rubber, it is possible to determine the amount of conventional CA 50/70 binder (7.95%) and crumb rubber (2%) to be used in the mixes prepared using the dry process. The amount of crumb rubber corresponds to 2.2% in relation to the weight the aggregate minerals to be used in the dry process (HMAR-D).

For the dry process, besides 2.2%, some mixes were also prepared with 3.6% to investigate the effect of rubber content on the mechanical behavior of these mixes. For all dry mixes, the binder content was fixed in 7.95%. The incorporation of crumb rubber was achieved by correcting the grain size distribution of the aggregates, considering the crumb rubber as part of the solid skeleton of the mixture.

Table 6 describes the proportion of each material used in the mixes using the dry process. The grain size corrections due to the substitution of granitic particles by crumb rubber are already included in Table 6. Numbers between brackets correspond to the percentage of rubber with respect to the mixture of mineral aggregates.

Table 6. Corrected compositions of mixes using the dry process.

Materials	**HMAR-D1 (2,2%)**	**HMAR-D2 (3,6%)**
Crumb rubber	2,0%	3,3%
Chips #1	10,0%	9,6%
Chips #0	28,7%	28,7%
Sand chips	48,1%	47,1%
Filler	3,7%	3,6%
Binder content	7,95%	7,95%

The procedure to produce hot mixes using the dry process included the following steps:

- Aggregate heating: mineral aggregates were proportioned and weighted and heat to the temperature of 177^{o}C in an oven for at least 2 hours;
- Rubber-aggregate mixture: crumb rubber was added to the previously heated mineral aggregates without filler and the mixture was homogenized for 15 seconds. Then pre-heated filler was added. This procedure avoids loss of filler during the mixture;

- Addition of binder: after the conventional binder reached the desired temperature, it was added to the mixture of aggregates, rubber and filler. The components were then mixed for a period not higher than 3 minutes;
- Compaction: the hot asphalt mix was compact immediately after taking from the mixing bucket;

Resilient modulus and fatigue life curves

Resilient modulus and fatigue tests were carried out according to the recommendations of AASHTO TP8/96. Beam type specimens have the following dimensions: 381 ± 6,35 mm in length, 50,8 ± 6,35 mm in height and 63,5 ± 6,35 mm in width. All specimens were subjected to accelerated long term aging as recommended by the norm AASHTO PP2/94. Tests were carried out with controlled strains, at a temperature of 20^{o}C and a load frequency application of 10 Hz.

Table 7 resumes the values of resilient moduli for all mixes studied here. The values do not show significant differences in the moduli of conventional and dry process mixes. The resilient modulus for the asphalt rubber mix (wet process) was higher than for the other mixes.

Table 7. Resilient moduli of hot mixes.

Mix type	**HMA-C**	**HMAR-D1 (2,2%)**	**HMAR-D2 (3,6%)**	**HMAR-W**
Resilient Modulus (MPa)	4319,5	4888,1	4485,3	5490,5

Figure 1 shows the fatigue life curves for all mixes studied here. The HMAR-D1 (dry process with 2.2% of rubber) presents the highest fatigue life, followed by the wet process mix and the dry process mix with 3.6% of crumb rubber. All mixes with rubber presented longer fatigue life than the conventional mix.

The curves of Figure 1 may be expressed in terms of the number of load cycles for the failure of the asphalt layer due to fatigue for an imposed value of tensile strains, in the following way:

$$N = k_1.\varepsilon_t^{k2}$$

where:

N: number of cycles to produce failure due to fatigue;

ε_t: imposed tensile strain;

k_1 and k_2: experimental constants.

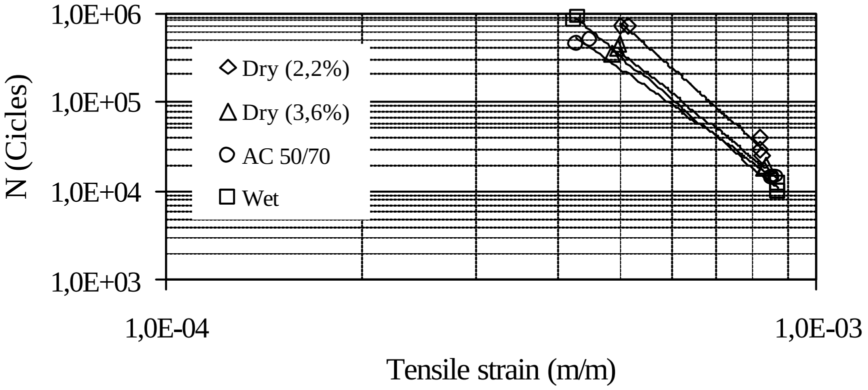

Figure 1. Fatigue life curves for the mixes.

Table 8 presents the experimental constants (k_1 and k_2) for the mixes studied in this paper.

Table 8 – Experimental constants for fatigue life curves

Type of mix	k_1	k_2
Conventional HMA-C	$2x10^{-12}$	-5,1631
Dry process, 2.2%, HMAR-D1	$3x10^{-16}$	-6,4743
Dry process, 3.6%, HMAR-D1	$2x10^{-14}$	-5,8391
Wet process, HMAR-W	$2x10^{-15}$	-6,1477

NUMERICAL SIMULATION OF PAVEMENT STRUCTURE CONSIDERING THE MECHANICAL PROPERTIES OF ASPHALT HOT MIXES MODIFIED WITH CRUMB RUBBER

Program used and input parameters

Program KENLAYER (7) was used in this paper to obtain the numerical solution for a flexible pavement subject to a uniform load distributed over a circular area. The behavior of the materials can be simulated with the following constitutive models: linear elastic, non-linear elastic, linear visco-elastic or any combination of the previous models.

A typical structure for pavement flexible pavements used in the Central Region of Brazil was adopted for present numerical simulations. The structure in founded on a lateritic clay subgrade, the base uses lateritic gravel with a thickness around 30 cm and the surface course uses dense asphalt hot mixes of variable thickness. The structure and the standard load are illustrated in Figure 2. The radius of the loaded area is obtained considering the standard simple axle with four tires with pressure of 560 kPa (80 psi) and total load of 82 kN. The values of resilient modulus for the subgrade and base materials were obtained from back analyses of several in situ tests in different areas of the Federal

District, Brazil (8). Figure 3 shows a plan view of the loaded area and a series of points spaced every 25 cm at which the vertical displacement were computed.

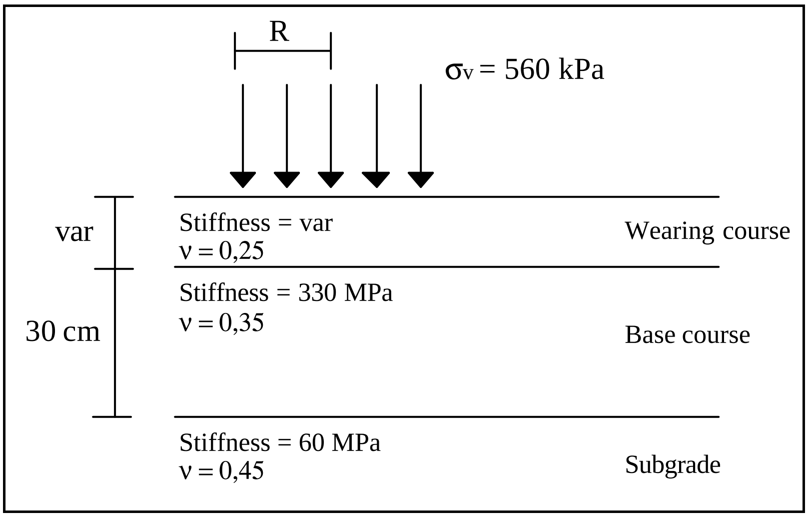

Figure 2 – Pavement structure and load.

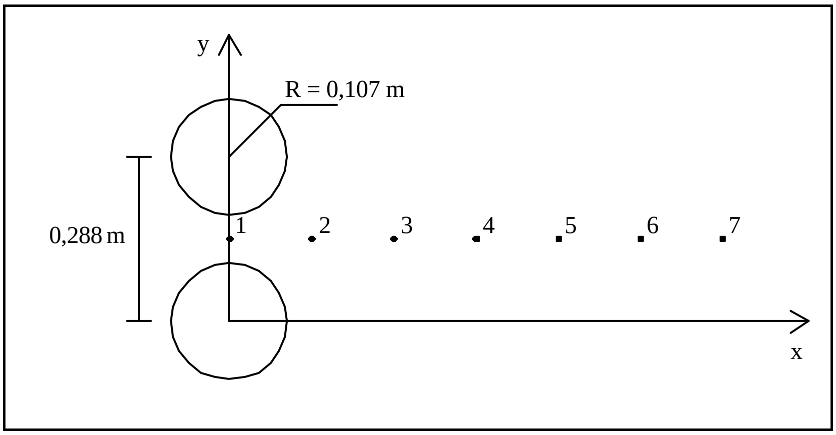

Figure 3 – Plan view of load area.

Results

Figure 4 shows the variation of the maximum tensile strain at the inferior fiber of the asphalt layer for the four mixes analyzed. The mixes were considered linear elastic and their thickness varied between 2.5 and 15 cm. For asphalt layer thickness greater than 5 cm, the tensile strains for the asphalt-rubber (dry and wet) materials were slight lower than those for the conventional (AC 50/70) mix. Differences among tensile strain of asphalt mixtures studied are compatible with resilient moduli values presented in the Table 7.

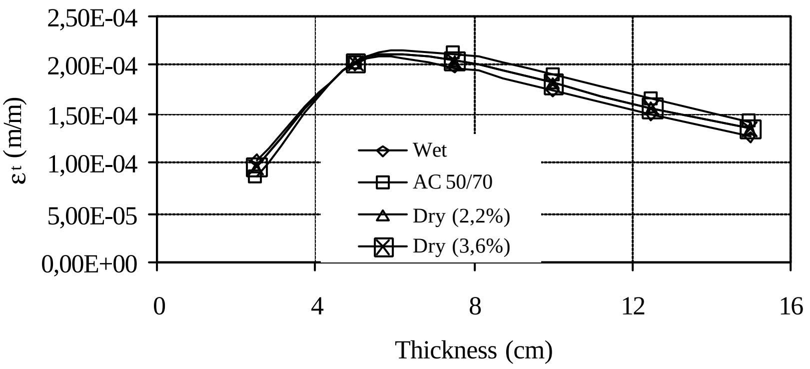

Figure 4 – Tensile strains.

Figure 5 shows the variation of fatigue life versus asphalt layer thickness. All mixes including rubber (dry or wet) showed significant gain in fatigue life when compared with the conventional mix. The best fatigue life performance in this case was for the dry mix with 2.2% of crumb rubber, followed by the wet mix (with the same amount) of rubber and the dry mix with higher rubber content (3.6%).

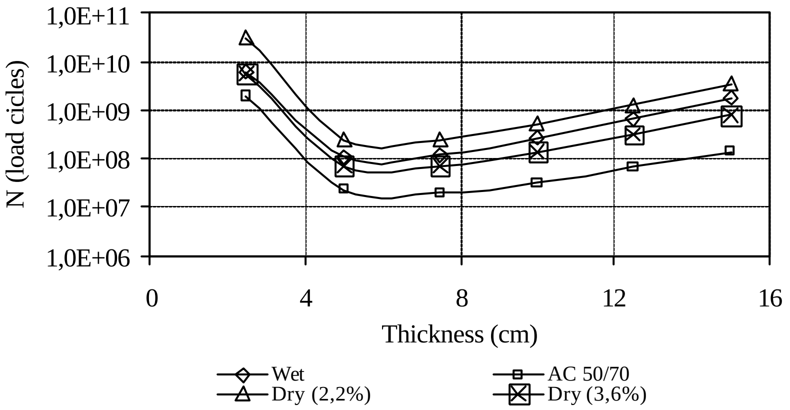

Figure 5 – Pavement fatigue life versus asphalt layer thickness.

Figure 6 shows the surface settlements for an asphalt layer thickness of 7.0 cm using the different materials. The results are very similar and also reflect the fact that the resilient moduli of the materials are not much different. This signals that one should be careful when judging the performance of different material based solely on in situ Benkelman beam or FWD tests. These testes may help to determine relative moduli of the layers using back analyses. However, what really affects the overall behavior of mixes modified with crumb rubber, either via wet or dry process, is their better fatigue life. For a full picture it is necessary to combine in situ tests, laboratory tests and mechanist analyses of the whole structure.

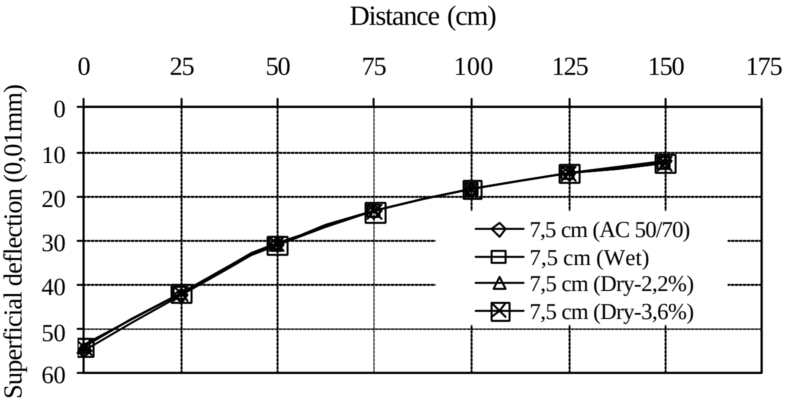

Figure 6 – Surface settlements for asphalt layers with thickness of 7.5 cm

CONCLUSIONS

The results present in this paper show that dense asphalt mixes incorporating crumb rubber, either via the dry or the wet process, present a better overall behavior when compared to conventional mixes. This is observed both in laboratory tests on the isolated materials and numerical analyses of a whole pavement structure.

The main improvement obtained with the incorporation of rubber is related to the gain in fatigue life of the asphalt mixes. The resilient moduli of the modified mixes do not change much when compared with the conventional ones. This similar deformability behavior is also reflects in the numerical analyses of the whole structure, which presented similar surface settlements in all cases analyzed here.

The results of fatigue life for dense graded asphalt hot mixes incorporating crumb rubber show a slightly better performance for the mixes produced via the dry process when compared to the mixes produced via the wet process, for the same material composition and volumetric conditions. However, one should not generalize this conclusion, since other results show a better fatigue life performance of the wet process when used in open graded hot asphalt mixes.

Other relevant aspects of the mechanical behavior of the mixes, such as resistance to rutting, should also be considered when comparing different options. Results of other works not presented here (1), show a significant gain in rutting resistance for mixes produced via the wet process when compared to conventional mixes. On the other hand the rutting resistance of mixes produced via the dry process was not much better than that observed for the conventional mixes.

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